The estimation of species richness at different altitudes on the northern slope of Changbai Mountain

HAO Zhan-qin, YU De-yong, YE Ji, JIANG Ping

(Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang 110016, P. R. China)

Abstract: By the method of gradient pattern analysis, 24 plots were set at altitudes 700-2600 m with an interval of 100 m on the northern slope of Changbai Mountains. Two non-parametric estimating methods, jackknife and bootstrap, were used to estimate the numbers of species in the communities at different altitudes. Results showed that the estimated numbers of species from bootstrap were more close to the reality. By comparing the difference between estimated number of species and the number of observed species, rationality of critical sampling area for different communities were validated.

Keywords: Estimation; Species richness, Changbai Mountains

CLC number: S718.54 **Document code:** A **Article ID:** 1007-662X(2002)03-0191-05

Introduction

The number of species in communities, namely species richness, is the oldest and most fundament concept of diversity. As for as diversity, this term hardly causes confusion so that its using rate is high (Liu 1997). Because of the difficulty of ascertaining species numbers of community completely by the investigation on the spot, the estimation of the species numbers always is the issue to biologist and ecologist. Accurate estimates are useful for comparing across different studies.

The northern slope of Changbai Mountain is species-rich. Previous investigations have shown large differences in community composition across and within altitudinal zones (Chen *et al.* 1964; Wang *et al.* 1980; Zhao 1980; Qian 1992; Liu 1989; Li *et al.* 1994; Hao *et al.* 2000). However, no study has yet systematically examined changes in species richness across an elevation gradient. By plot layout and investigating the vegetation, whether non-parametric estimation methods suiting to study community diversity in Changbai Mountain region or not must be clarified.

Conditions of the studied site

The research was focused mainly on the north slope of Changbai Mountain at the altitude of 700-2 600 m. The sampling site at the altitude of 700 m is located at east longitude 128°28′, north latitude 42°24′ and the north edge of Changbai Conservation. The sampling site at the altitude of 2 600 m is located at east longitude 128°05′, north latitude 42°01′, near the weather station. Other climate factors at every altitude see Table 1.

Methods

Plot layout

Gradients pattern method was taken for setting plot, namely from altitude of 700 m to the top of the mountain 2 600 m. A plot was set along with altitude going up each 100 m; total twenty plots were set. The area of plot from altitude of 700 m to 1 900 m was 32 m×32 m; the plot area of alpine tundra zone over altitude of 2 000 m was 16 m×16 m. At altitudes of lower than 1 900 m, each plot consisted of sixteen sub-plots with its area of 8m×8m each; total areas were 32 m×32 m=1 024 m^2. In alpine tundra of altitude of 2 000 m and higher, each plot consisted of four sub-plots with its area 8 m×8 m each; total areas were 16 m×16 m=256 m^2.

Items and methods of the investigation

For trees with height lower than 1.3 m, species, heights and growing conditions were recorded. For trees with height higher than 1.3 m, species name, diameter at breast high, growing conditions (perishing or normal) were recorded and height estimated by eyes. For shrub and herb species, species name, abundance, average height, stem density, and conditions of the local habitat (such as growing on fallen trees or in opening) were recorded.

Non-parametric estimation methods

Among the methods of calculating or estimating species richness, the simplest one is to simply count species in sample plots. However, total species number relies heavily on the size of the sample plot (McCune & Mefford, 1999). Whether the size of plot is large or small, species richness will always be underestimated. Of course, the extent of underestimation decreases as plot area increases. Many parametric and non-parametric methods have been used

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Foundation item: This paper is supported by Chinese Academy of Sciences (a grant KZCX-406) and Chinese Academy of Sciences "100 people" project..

Biography: HAO Zhan-qing (1962-), male, Ph Doctor, Professor in Institute of Applied Ecology, Chinese Academy of Science, Shengyang 110016, P. R China E-mail: hzq@iae.ac.cn

Received date :2002-04-01

Responsible editor Chai Ruihai

to correct for underestimation in plot data. Liu Canran *et al.* (1997) introduced the details of these methods. This paper only explores the application of some non-parametric methods.

Table 1. Variation of climate factors along the elevation on northern slope of Changbai Mountain

A (m)	AT/Y (°C)	P/Y (mm)	>5°C AT(°C)	6-9P (mm)	AI	MI	ATJ1 (°C)	ATJ2 (°C)	D (day)	SD (day)
700	2.83	679.18	2459.77	483.02	0.67	1.91	-17 33	19.63	121.00	130.79
800	2.32	703.62	2285.25	500.40	0.63	2.21	-17.64	19.07	116.54	137.58
900	1.81	728.95	2123.12	518.41	0.59	2.52	-17.95	18.51	112.25	144.37
1000	1.29	755.19	1972.49	537.07	0.56	2.82	-18.27	17.95	108.12	151.16
1100	0.78	782.37	1832.55	556.40	0.53	3.12	-18.58	17.40	104.14	157.94
1200	0.27	810.53	1702.53	576.43	0.50	3.43	-18.89	16.84	100.31	164.73
1300	-0.24	839.70	1581.74	597.18	0.47	3.73	-19.21	16.28	96.62	171.52
1400	-0.75	869.92	1469.52	618.67	0.44	4.04	-19.52	15.73	93.06	178.31
1500	-1.26	901.23	1365.26	640.94	0.42	4.34	-19.83	15.17	89.64	185.10
1600	-1.78	933.67	1268.40	664.01	0.39	4.65	-20.15	14.61	86.34	191.88
1700	-2.29	967.28	1178.41	687.91	0.37	4.95	-20.46	14.06	83.16	198.67
1800	-2.80	1002.09	1094.81	712.67	0.35	5.26	-20.77	13.50	80.10	205.46
1900	-3.31	1038.16	1017.13	738.32	0.33	5.56	-21.09	12.94	77.15	212.25
2000	-3.82	1075.53	944.97	764.89	0.31	5.87	-21.40	12.39	74.31	219.04
2100	-4.33	1114.24	877.93	792.42	0.29	6.17	-21.71	11.83	71.58	225.82
2200	-4.84	1154.34	815.64	820.94	0.28	6.48	-22.03	11.27	68.94	232.61
2300	-5.36	1195.89	757.77	850.49	0.26	6.78	-22.34	10.71	66.40	239.40
2400	-5.87	1238.93	704.01	881.10	0.25	7.09	-22.65	10.16	63.96	246.19
1500	-6.38	1283.52	654.06	912.81	0.23	7.39	-22.97	9.60	61.61	252.98
2600	-6.89	1329.72	607.66	945.67	0.22	7.70	-23.28	9.04	59.34	259.76

Note: A: altitude, AT/Y : the average temperature of one year, P/Y : the precipitation of one year, AT: accumulative temperature of one year, P: precipitations of the three months, AI: aridity index, MI: moisture index, ATJ1: the average temperature of January, ATJI2: the average temperature of July, D: the days with no frost , SD: the days of existing snow.

* (cited from Chizhengwen etc, 1981)

The most common non-parametric methods include Jackknife serials and bootstrap. Jackknife and bootstrap were used originally to estimate SD and D. Zahl (1997) first applied them to estimate species richness. He regarded the rectangle or square plot as the independent specimen, plot but non-life individual as random specimen (McCune & Mefford 1999). In fact, the random nature of plot takes on a kind of spatial random nature. There is no need for non-parametric method such as Jackknife and bootstrap to suppose something for the relationship among species in sampling plot and statistical distribution of species.

The method of Jackknife includes a 1st-order and 2nd-order Jackknife. The 1st-order Jackknife is the function of rare species recorded in the community. Its estimated value (Palmer 1990,1991) is:

$$J_1=s+r_1(n-1)/n \quad (1)$$

Where: S is the numbers of recorded species; r_1 is the number of species which appear only in one plot; n is the number of plot, J_1 is species number for 1st-order Jackknife.

The 2nd-order Jackknife estimate is the function of species that number appear only in two samples. The estimated value (Palmer, 1997) is:

$$J_2=s+r_1(2n-3)/n-r2(n-2)2/(n(n-1)) \quad (2)$$

Where: r_2 is the number of species appearing only in two samples, and J_2 is species number of 2nd-order Jackknife. When the value of r_1 is 0 and the value of r_2 is more than 0, the estimated number of species can be lower than the measured species numbers.

The method of bootstrap is firstly created by Efron (1979,1981); its estimated value is (McCune & Mefford 1999):

$$B_j=S+\sum_{j=1}^{s_0}(1-Y_j/n)^n \quad (3)$$

Where Y_j is the numbers of samples; B_j is the numbers of species estimated by bootstrap method.

Non-parametric methods can produce more accurate estimates of species richness than estimates derived solely from counts in sample plots (McCune & Mefford 1999; Hellmann & Gray 1999). Furthermore, these techniques can provide an estimate of sample size adequacy, and can partially overcome differences in the species-area rela-

tionship, thereby allowing for direct comparison among different communities.

Results and analysis

Large differences between measured and estimated values occurred at low altitude zones (below 900 m), especially in the broad-leaved-Korean pine forest at altitude of 700 m (Table 2). This results stem from the fact that Jackknife estimates are based on species that appear only in one or two plots. There are many relatively rare species in broad-leaved-Korean pine forests that did not appear in any of our sample plots. This resulted in large jackknife estimates, and indicated that the sample area was too small for broad-leaved-Korean pine forest. In the forest community above 1 100 m, the estimated value was near the measured value; especially for the 1st-order jackknife and bootstrap methods. Sample area was apparently adequate to capture most species in dark-conifer forest.

Table 2. Number of tree species estimated for communities at different altitudes

Alt.(m)	S/P	S/SP	SD	Range	J_1	J_2	B_i	r_1	r_2
700	19	3.688	1.448	5	27.4	35.3	22.4	9	0
800	20	10.56	2.683	7	21.9	23.6	20.8	2	0
900	14	6.000	1.826	6	16.8	19.4	15.1	3	0
1000	17	4.250	1.807	6	20.7	21	19	4	4
1100	13	6.625	1.360	4	13.9	12.4	13.7	1	3
1200	14	7.688	1.195	4	14	10.7	14.5	0	4
1300	12	7.438	1.263	4	12	11.2	12.1	0	1
1400	10	5.625	0.957	3	11.9	12.8	10.8	2	1
1500	9	4.438	1.263	4	10	12.6	9.9	2	0
1600	6	3.875	1.025	4	6	5.2	6.1	0	1
1700	7	3.563	0.892	3	7.9	8.8	7.4	1	0
1800	5	1.500	0.632	2	6.9	8.6	5.8	2	0
1900	5	2.313	0.793	3	5	3.4	5.3	0	2

Note: S/P is the observed number of species in each plot; S/SP is the average number of species in each sub-plot. Same for other tables.

In comparison to the estimates for tree species, the jackknife and bootstrap estimates for shrub and herb species were much greater than the number of species encountered on the plots (Table 3). Differences were greatest at low altitudes, especially at the altitude of 700 m. There were relatively small differences, however, at high altitudes, and sometimes the jackknife and bootstrap estimates were very similar to the number of species counted on plots.

The results estimated for richness of all plant species in the community were fundamentally consistent with the results for the respective layers (Table 4). The species numbers estimated by the methods of 1st-order Jackknife, 2nd-order Jackknife and bootstrap were higher than species numbers counted from sample plots, Differences between estimates and counts were greatest for communities that had larger numbers of rare species.

Among the three estimated values, the bootstrap estimate generally produced the smallest values, and was closest to the measured species richness; the 1st-order Jackknife was intermediate and the 2nd-order Jackknife was the largest, but sometimes it was less than the 1st-order Jackknife value, and even less than the measured value. The difference between the measured value and the estimated values was influenced by numbers of rare species in the community. The communities with the highest richness had the greatest proportion of rare species and the greatest difference among estimates.

Discussion

The estimation for species richness commonly concerns with such questions: 1) in contrast to true conditions, Are these estimations high or low? 2) If this kind of estimation can be repeated; if there is consistency with quadratic estimation? 3) How much extent was the estimation value near to the true value (McCune and Mefford 1999). In most cases, non-parametric estimates of species richness are greater than counts of species on sample plots. These estimates are therefore consistent with the concept of the species-area curve. Because there are no precise records about the communities on the north side of Changbai Mountain, there is no methodology to evaluate the precision of every method. But species numbers estimated by the method of non-parameter are close to the results of some researches about the corresponding community and the altitude (Qian 1992; Liu, 1989; Li *et al.* 1994; Hao *et al.* 2000).

The method of non-parametric (Jackknife and bootstrap) can get better results on the condition that there are more many measured species or in contrast to total species numbers, there are few rare species (Liu 1997). Because these data used by these methods are binary data (namely, existing or non-existing) but not abundance data; simultaneously these methods are on the basis of sampling

specimen, so that they can be used to estimate species richness of the community.

Precision of the method of species-area curve, which is used to estimate species numbers in the community to a large extent, relies on the representation of the specimen, dimension of sampling and the relevant community (Liu *et al.* 1997). The validity of the estimation about species numbers by applying measured data to process these models should be limited in the sampling zone; any conclusion derived from out it has its limitation.

The estimation of species numbers at respective altitudes reflects the rationalization of plot setting and sampling area. In the total, except that sampling area in the broad-leaved-Korean pine forest at altitude of 700 m was rather too little, sampling area in other communities may meet with the need of the research.

Table 3. Number of shrub and herb species estimated for communities at different altitudes

Alt. (m)	Layer	S/P	S/SP	SD	Range	J_1	J_2	B_l	r_1	r_2
700	SB	20	5.38	1.20	4	29.4	36.5	23.8	10	2
	HB	61	22.69	4.70	16	70.4	69.3	66.2	10	12
800	SB	15	4.13	0.72	2	18.7	19	17	4	4
	HB	42	13.94	6.04	21	53.2	60.5	47.0	12	4
900	SB	15	7.69	1.49	5	15.9	16.8	15.4	1	0
	HB	32	11.56	3.22	11	43.2	52.9	36.5	12	1
1000	SB	14	6.31	1.70	7	14.9	14.2	14.6	1	2
	HB	45	15.63	5.19	20	56.2	62.7	50.1	12	5
1100	SB	9	3.94	1.12	4	9.9	10.8	9.4	1	0
	HB	32	15.50	2.97	12	36.7	37.8	34.3	5	4
1200	SB	8	4.31	1.14	4	8	7.2	8.1	0	1
	HB	22	11.88	2.25	8	25.7	29.2	23.6	4	0
1300	SB	7	1.75	0.93	4	7.9	8	7.6	1	1
	HB	25	13.00	3.25	10	26.9	26.2	26.1	2	3
1400	SB	8	3.63	1.03	3	8	7.2	8.2	0	1
	HB	39	19.38	2.31	10	43.7	42.3	41.7	5	7
1500	SB	8	3.75	1.00	3	8.9	9	8.4	1	0
	HB	59	27.69	3.54	13	67.4	70.4	63.1	9	6
1600	SB	4	1.44	0.63	2	4.9	5.8	4.4	1	0
	HB	39	23.63	2.42	9	44.6	49.9	41.2	6	0
1700	SB	8	2.00	0.89	3	11.7	14.4	9.6	4	1
	HB	40	20.94	2.65	9	44.7	46.6	42.2	5	3
1800	SB	7	3.44	1.21	4	7	5.4	7.3	0	2
	HB	47	21.44	4.49	17	57.3	64.5	51.4	11	3
1900	SB	8	5.25	1.00	4	8.9	9	8.5	1	1
	HB	22	8.56	2.48	8	26.7	29.4	24.2	5	2
2000	SB	6	5	0	0	6	5.7	6.1	0	1
	HB	30	15.25	3.40	7	39	42	34.4	12	9
2100	SB	8	6.50	1.00	2	8.8	9.2	8.3	1	0
	HB	23	11.25	2.99	7	30.5	33.8	26.5	10	5
2200	SB	7	4.75	0.96	2	9.2	10.7	8	3	0
	HB	19	13.00	.82	2	22	22.3	20.6	4	5
2300	SB	5	4.00	0.82	2	5.8	6.2	5.3	1	0
	HB	20	14.25	3.86	8	21.5	20.8	21.0	2	5
2400	SB	9	5.25	1.26	3	11.2	12.1	10.1	3	2
	HB	13	8.75	1.71	4	16	17.7	14.3	4	1
2500	SB	6	4.75	0.96	2	6.8	6.9	6.4	1	1
	HB	18	12.25	3.20	7	21	21.3	19.6	4	5
2600	SB	2	2.00	0	0	2	2	2	0	0
	HB	15	14.25	.96	2	15	15	15	0	0

SB: Shrub; HB: Herb

Table 4. Plant species estimated for communities at different altitudes

Alt. (m)	S/P	S/SP	SD	Range	J_1	J_2	B_i	r_1	r_2
700	100	31.75	5.87	23	127.2	141.1	122.5	29	14
800	77	28.75	8.23	28	93.9	103.1	84.7	18	8
900	61	25.13	4.32	16	76	89.2	67	16	1
1000	76	26.31	6.96	23	91.9	97.8	73.7	17	11
1100	54	26.13	3.12	10	60	61	57.4	7	7
1200	44	23.94	2.89	8	47.7	47.2	46.2	4	5
1300	44	22.25	4.57	15	46.8	45.4	45.8	3	5
1400	57	28.63	2.36	7	63.6	62.3	60.7	7	9
1500	76	35.94	4.30	16	87.2	92.8	81.3	12	6
1600	49	29.00	2.85	12	55.6	60.9	51.8	7	1
1700	55	26.50	2.56	9	64.4	69.9	59.2	10	4
1800	59	26.38	4.15	16	71.2	78.5	65.7	13	5
1900	35	16.13	3.56	13	40.6	41.8	38	6	5
2000	39	21.75	3.30	7	49.5	53.2	44.1	14	10
2100	33	18.50	1.92	4	44.2	49.8	37.2	12	6
2200	27	18.25	1.89	4	32.2	33.7	29.6	7	6
2300	25	18.25	3.78	7	27.2	27.1	26.3	3	5
2400	22	14.00	2.16	5	27.2	29.7	24.4	7	3
2500	24	17.00	3.37	7	27.7	28.2	26	5	6
2600	17	15.75	0.96	2	17	17	17	0	0

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